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DEVELOPMENT OF A PROTOTYPE AIRCRAFT COUNTER - PHASE I

Final Report

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DEVELOPMENT OF A PROTOTYPE AIRCRAFT COUNTER - PHASE I

by

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for

Transportation Development Centre
Montreal, Quebec

December, 1987

"The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre."

Un sommaire en français de ce rapport est inclus avant la table des matières.

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17. Abstract

This report summarizes the conclusions and recommendations arrived at as a result of a feasibility study for the development of a prototype aircraft counter. Two feasible sensors for the counter were identified - an FM-CW radar and an acoustic gates system based on two microphones. The report summarizes the system design and recommendations for the production and evaluation of a prototype aircraft counter.

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17 Résumé

Ce rapport résume les conclusions et les recommandations d'une étude de faisabilité concernant un compteur d'aéronefs à réaliser en prototype. Deux procédés ont été retenus: radar à ondes entretenues, à modulation de fréquence et portes acoustiques formées de deux microphones distants. Le rapport présente également les grandes lignes de la conception du système envisagé et des recommandations relatives à la fabrication et à l'évaluation d'un prototype.

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SUMMARY

This report presents the conclusions of a study undertaken by the Transportation Development Centre into the feasibility of developing and field-testing aircraft counters. The study was performed by Canadian Astronautics Limited under DSS Contract number T8200-6-6519/01-SD, entitled "Development of a Prototype Aircraft Counter - Phase 1". The start date of the contract was April 8, 1987.

The objective of the study was to develop a prototype aircraft counter in order to provide counts of landings and takeoffs at Canadian airports. This is a small task in the more global Transport Canada objective of developing tools to forecast future system needs in support of airport design and services for the improvement of safety, efficiency and productivity in Canadian air terminal operations.

The major topics addressed in this study include:

- Counting requirements, in terms of classes of aircraft and counting rates.
- Classification requirements.
- Data storage and recall/display functions.
- Environmental characteristics and restrictions.
- Packaging and mounting considerations.
- Local and remote operations.
- Reliability, maintenance and availability considerations.
- Electrical specifications, including battery options.
- Data interpretation and special processing capabilities.

The technical approaches studied included radar, acoustic, VLF loops, beam-interception and magnetic anomaly detectors. As a result of the feasibility study, it was found that two sensors were well suited to meet the requirements of the aircraft counter. One was a frequency modulated continuous wave (FM-CW) radar, and the other was a system consisting of two spatially separated microphones, referred to as acoustic gates. These two were the only suitable candidate sensors, if a rough

classification of aircraft type was considered essential. If classification is not required, a Doppler radar similar to a police radar could also be considered. The sensor design focussed on the FM-CW radar and acoustic gates, since these were found to meet the requirements of classification and landing/takeoff discrimination more easily than other techniques. The radar sensor was designed in detail, using an FM-CW altimeter concept. Not many data were available on the acoustic signatures of aircraft in the required form. It was also not clear if the acoustic sensor would detect aeroplanes landing under low power. In order to get more information, field measurements were made at the Ottawa International airport, and at Carp airport.

A system trade-off study was also performed, to arrive at a suitable system configuration. This trade-off compared isolated aircraft counters at each end of the runway with a totally integrated airport system with all sensors connected to a central processor. The advantages of an isolated counter for each runway include the fact that no communications links are required across the runway complex. Further, since the counter will not be used as an operational tool, it is not important that all the data collected be accessible in real time. The advantage with a network of aircraft counters, all connected to a central control processor, is that the data may be collected at a central location in real time. This may be necessary as a future enhancement, but is not considered essential at the evaluation stage. Another advantage with a centralised system is that problems with an aircraft counter at the end of a runway can be quickly detected and corrected, which is not the case with an isolated counter. It is recommended that, for the evaluation phase, an isolated aircraft counter be used, in order to overcome problems of communication between the end of the runway and a central location in the airport complex.

It is recommended that, for evaluation, an aircraft counter with dual sensors, radar and acoustic, be used. The packaging of such a system was studied. It is suggested that the processor and interfaces to the radar and acoustic sensors be mounted in a box similar to those used by the telephone and cable companies. The electronics would be above the snow line, and protected from extreme weather conditions. The placement of the sensors with respect to runways was also studied. In order to satisfy height restrictions for objects in the vicinity of runways, the aircraft counter must be placed away from the axis of the runway, at a distance of about 60 metres from the end of the runway. The radar sensor would consist of a parabolic dish antenna of diameter roughly 50 cm placed on one box. Beside it would be one of the microphones for the acoustic sensor. The other microphone would be placed on a pole 60 meters away from the first. The data collected by the counter would be stored in its own battery-backed memory, which is large enough to hold 90 days worth of data. This may be read at any time using a portable computer.

Finally, cost estimates were prepared for Phase II, which involves the implementation of a prototype; Phase III which includes evaluation at an airport; and manufacture . For estimating the cost of production, a quantity of 30 was assumed. Phase II costs were estimated at roughly $300 K for each sensor, if they were implemented separately, or $365 K if implemented as one package, reflecting the saving achieved by sharing the common elements, mainly the processor, data storage and accompanying software. The cost for the evaluation (Phase II) was estimated at $96 K. In production lots of thirty, the cost of a dual sensor aircraft counter was estimated at $12K. This assumed that no redesign was required after the evaluation. The cost of the acoustic sensor could be reduced by substituting less expensive microphones. The effects of this must be determined during the evaluation phase. The reduction in cost achieved by using only one sensor is not high. For instance, removing the acoustic sensor would reduce the total cost per counter by approximately $1K. Removing the radar would reduce the cost per counter by $2K-$3K, over 30 units.

SOMMAIRE

Ce rapport présente les conclusions d'une étude lancée par le Centre de développement des transports sur les techniques utilisables pour le comptage d'aéronefs: faisabilité et essais in situ. L'étude a été confiée à la Canadian Astronautics Limited aux termes d'un marché conclu avec le MAS sous le n° T8200-6-6519/01-SD, intitulé "Development of a Prototype Aircraft Counter - Phase I" et entré en vigueur le 8 avril 1987.

Cette étude avait pour objectif de mettre au point le prototype d'un compteur d'aéronefs devant servir à connaître le nombre d'atterrissages et de décollages dans les aérodromes du Canada. Elle se fonde dans l'objectif plus vaste de Transports Canada qui est de mettre au point des moyens de prévision du trafic aérien, à l'appui des services de conception et d'exploitation des aéroports, dans le but d'accroître la sécurité, l'efficacité et la productivité des opérations aériennes terminales au Canada.

Les grandes lignes de l'étude ont été les suivantes:

- Paramètres de comptage : catégories d'aéronefs et débits à compter;

- Exigences de classification;

- Stockage, recheche et affichage des données;

- Données et contraintes propres à l'environnement;

- Assemblage et mise en place;

- Opération locales et télécommandées;

- Fiabilité, maintenance et disponibilité;

- Caractéristiques électriques, y compris des compteurs alimentés par une batterie d'accumulateurs;

- Interprétation des données et fonctions spéciales.

Les techniques de comptage envisagées par l'étude ont été les suivantes: le radar, l'acoustique, les boucles très basse fréquence, la photodétection et le magnétisme. L'étude de faisabilité a montré que deux procédés son utilisables: celui du radar à ondes entretenues à modulation de fréquence et celui des portes acoustiques formées de deux microphones distants. Ce sont les deux seuls procédés utilisables si l'on tient pour essentielle une classification grossière des aéronefs. Sinon, un cinémomètre radar à effet Doppler semblable à celui qu'utilisent les corps policiers serait suffisant. Les études de conception

ont été faites seulement à l'égard des deux procédés retenus étant donné que ceux-ci répondent aux exigences de classification des aéronefs et de discrimination atterrissage-décollage, mieux que tout les autres. Un projet détaillé du capteur radar a été produit, fondé sur le principe de l'altimètre à modulation de fréquence. Quant au procédé acoustique, on ne disposait que peu d'information sur la signature acoustique des aéronefs et, de plus, on ne savait pas trés bien encore s'il pouvait servir à détecteur un aéronef atterrissant à faible régime moteur. Afin d'enrichir la base de données acoustiques, une campagne de mesurage a été lancée à l'aéroport international d'Ottawa et l'aéroport Carp.

Une étude comparative a été également faite afin de connaître lequel des deux systèmes serait le plus approprié: un système comportant des compteurs isolés situés aux extrémités des pistes, en un autre intégré où tous les compteurs forment un réseau relié à un processeur central. L'avantage du premier est le fait qu'aucune liaison n'est nécessaire entre le compteurs. (Comme ces capteurs ne doivent pas servir à titre d'outil opérationnel, il n'y a aucun besoin d'exloiter les données.) L'avantage du second système est que les données peuvent être exploitées en temps réel. Cet affinement pourra s'avérer utile à l'avenir, mais pas au stade actuel qui est celui de l'évaluation. Un autre avantage du système centralisé, que le système isolé n'a pas, est que toute anomalie dans un compteur pourra être immédiatement détectée et corrigée. Il est recommandé que, pour les besoins de l'évaluation, on se contente d'un compteur isolé, en attendant de résoudre le problème de la liaison à mettre en place entre les compteurs en bout de piste et un processeur central.

Le système dont la mise en place est recommandée pour les besoins de l'évaluation devrait comporter deux capteurs: un capteur radar et un capteur acoustique. Après étude de l'assemblage d'un tel système, il est préconisé que le processeur et les interfaces radar et acoustiques soient montés dans un boîtier semblable à celui utilisé par les compagnies de téléphone et de câblodistribution. L'électronique se trouverait au-dessus de la limite d'enneigement et protégée contre les intempéries. L'emplacement des capteurs par rapport aux pistes a également été étudié. Pour respecter les servitudes aéronatiques obligatoires à proximité d'une piste, le détecteur devra être placé à l'écart de l'axe de piste, à quelque 60 m de l'extrémité de celle-ci. Le capteur radar comporterait une antenne parabolique de quelque 50 cm de diamètre, placée sur l'un des boîtiers avec, à côté, l'un des deux capteurs acoustiques, le second étant placé sur un poteau à 60 m plus loin. Les données du compteur seraient stockées dans une mémoire particulière à celui-ci, alimentée par batteries et dont la capacité de stockage serait de 90 jours environ. Les lectures pourront se faire à tout moment, à l'aide d'un ordinateur portatif.

Enfin, un devis estimatif a été fait à l'égard de l'étape II (mise en place d'un prototype), de l'étape III (évaluation in situ) et de la fabrication fondée sur une production de 30 unités. Il a été calculé que l'étape II coûtera autour de 300 000 $ par capteur, si les deux capteurs ne sont pas sous un mème boîtier, et de 365 000 $ s'ils le sont, mettant en évidence l'économie réalisable grâce à la mise en commun du processeur, de la mémmoire et des logiciels. Il a été également calculé que l'étape III (évaluation) coûtera dans les 96 000 $. En production d'une série de 30, un compteur bimode reviendra à 12 000 $, compte non tenu de la nécessité éventuelle de réétudier le compteur à l'issue de l'évaluation. Le capteur acoustique pourra coûter moins cher en utilisant des microphones de qualité moindre; l'effet de cette substitution devra être déterminé lors de l'évaluation. L'emploi d'un compteur à capteur unique n'apportera pas de fortes économies. L'élimination du capteur acoustique ne réduira la coût total que d'un millier de dollars par compteur, alors que la suppression du capteur radar apportera des économies de 2 à 3 000 $ par compteur, le lot de fabrication pris en compte étant toujours de 30 unités.

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1. INTRODUCTION

Transport Canada (TC) supports a wide variety of technical and operational activities at Canadian airports. In order to improve safety, efficiency and productivity in Canadian air terminal operations, TC requires a wide variety of data concerning airport operations. One such datum of importance is a measure of aircraft activity at a terminal. Such information could be used to tailor the services at the air terminal to be optimal for the level of activity. Decisions to upgrade an air terminal would depend to a large extent on data regarding aircraft activity. Thus, there is a need to develop a reliable system for gathering such data automatically.

The Remote Aircraft Counter is a stand-alone sensor system integrated with a processor, used to count aircraft landing or taking off at airports. The requirements for the Remote Aircraft Counter, as well as an initial trade-off study comparing various possible sensors, are described in a previous document entitled "Feasibility Study for the Remote Aircraft Counter". In that document various sensors, including radar, acoustic, very low frequency (VLF) loops, magnetic anomaly detectors, and beam-interception techniques were discussed. The general conclusion was that frequency modulated continuous wave (FM-CW) altimeter type radars and passive acoustic sensors were the most suitable for the Remote Aircraft Counter. These two sensors allowed classification of the aircraft for low additional cost. If there is no requirement for aircraft classification, additional sensors like the CW radar (Doppler) and VLF loops could also be considered.

2. OBJECTIVES OF THE STUDY

The major objectives of this study were to investigate available technologies that may be used for accurate counting of aircraft activity in remote airports; pick a few of the most promising techniques; study these in greater detail; design a system based on one or more of the sensors, that would satisfy the requirements of Transport Canada; and finally provide a prototype production and evaluation plan, along with an estimate of the cost.

The emphasis on aircraft counting was directed towards remote airports. However, it was recognized that there were potential uses for aircraft counters at busy airports as well. Therefore, the study was not to be restricted to any class of airport.

In addition to counting aircraft landings and takeoffs, further objectives of the study included designing,if shown to be feasible, a system that could classify aircraft, as well as discriminate between takeoff and landing activities.

3. METHODOLOGY

The study was organized into four main activities. The first was to establish a set of requirements for the aircraft counter. This included establishing operational, accuracy, environmental and reliability requirements. The second phase involved a survey of available technologies, and investigation of their suitability as aircraft counters. This was reviewed with Transport Canada and the Transportation Development Centre (TDC). Criteria were developed to select the most suitable candidates from available sensor technologies. The goal of this phase was to arrive at a consensus, within the project team and with TC and TDC, on the best candidate (or candidates) for further study. The third step in the study was to do a more detailed design for these sensors, as well as a system design. It was intended that the system design would study a few alternate configurations for system implementation, and recommend a suitable system architecture. The last activity was the proposal of a suitable prototype production plan, along with a cost estimate.

In order to ensure progress towards these objectives, frequent progress meetings were scheduled, and held. These were to serve as a forum for arriving at a consensus on requirements, and the suitability or otherwise of different system options, as well as a method by which the contractor could obtain information that Transport Canada either published or could access easily.

Further, five milestone events were identified early in the project. These were tied to the production of four reports. The first document to be produced was the project plan. This was intended to summarise the scope of the work, plans for carrying out the work, the expected deployment of the available man-power resources, as well as to establish a cash-flow, to ensure that all the required work can indeed be done in the required time and within the financial limitations. The second document, entitled "Feasibility Study for the Remote Aircraft Counter", was to deal with all the requirements for the aircraft counter, as well as outline various technologies that could be used for sensors. The third document, entitled "Design Document for the Remote Aircraft Counter" was to deal with one or more selected sensors in sufficient detail, to establish the practicality and suitability of the chosen technology. This document would also include a study of various system options for the use of the aircraft counter at an airport, with all the restrictions that normally apply to instruments at airports.

This document would also include the prototype development and evaluation plan. The plan would include the estimated cost for developing and field-testing a prototype aircraft counter. The last document is this final report, which summarizes the conclusions of the study and recommendations for future action.

4. SYSTEM REQUIREMENTS DEFINITION

The first major task of the study was to define requirements that should and could be met by a useful aircraft counter. This was accomplished with the help of TC and TDC.

Through meetings with TDC and TC, and through a literature survey of airport operations and operating environment, a set of sensor and system requirements were defined early in the project. These are described in detail in the Feasibility Study report. The requirements apply essentially to the prototype model, although many may apply to the production version as well. Most of the environmental, size, documentation and training requirements would be more stringent for the production version than specified below.

1) DETECTION

The aircraft counter shall be capable of detecting all common aircraft other than helicopters using runways, during takeoff and landing operations. The counter shall be capable of discriminating between takeoff and landings. It must resolve two distinct operations that are separated in time by at least 20 seconds.

2) CLASSIFICATION

It is desirable that the aircraft counter be able to classify aircraft using suitable criteria, like aircraft noise, radar reflectivity, size or other parameter. However, it is essential that the counter discriminate between flying and non-flying objects within the vicinity of airports, and also between aircraft and flocks of birds.

3) ACCURACY

The aircraft counter shall have a count accuracy of 90%. The absolute value of the error in aircraft counts over a period of three months shall be less than 10%. In order to gain confidence in the estimates of accuracy, it is necessary to calculate the accuracy over a sufficiently large sample. The size of the required sample depends on the frequency distribution of the relevant data, in this case the aircraft counts. This distribution is not known a priori. Hence, for the definition of

accuracy, we assume that the number of operations (landings and takeoffs) should be of the order of 1000, which should be observable at any airport in a reasonable length of time, say three months.

4) STORAGE

The aircraft counter shall be capable of storing the runway and airport ID; the type of operation (landing/takeoff); the time to the nearest 10 seconds; and the class of aircraft. Enough memory shall be provided to store this information collected over a three month period. For sizing the memory, it is assumed that a typical airport would support 360 operations per day.

5) USER FRIENDLINESS

It is expected that the aircraft counter will be operated by technicians, not specifically trained to operate computers. A simple, user-friendly interface to the counter is most desirable.

6) SECURITY

No special security restrictions are necessary, other than those imposed to maintain system integrity and reliability.

7) ERROR RECOVERY

It is envisaged that the aircraft counter will be left to run for stretches of time (3 months) without any check made on its operation. Hence, it should be as fault-tolerant as possible. Failure of a sensor shall be detected and flagged. No data from a failed sensor should be included in the statistics.

8) SELF-DIAGNOSIS

The aircraft counter shall be capable of performing built-in tests, and reporting any malfunctions detected.

9) ENVIRONMENT

The aircraft counter shall be designed to work in the normal electromagnetic and noise environment around an airport. In addition, it should not interfere with ground support equipment or avionics instrumentation.

The aircraft counter shall be designed to work in all common weather conditions, maintaining a count accuracy of 90% over any 3 month period.

All outdoor equipment shall be designed to meet the requirements of Category 2 outdoor environment, as specified by DFS1000 (TP3131). Indoor equipment will meet the requirements for

category 5 environment.

10) POWER

The aircraft counter shall use the normal power available at airports. Where such power is not available, other optional power sources shall be considered.

11) SIZE

The aircraft counter shall meet size requirements dependent on its location with respect to the runway. Transport Canada report TP1247E shall be used as the guideline for size. In addition, the aircraft counter shall also be frangible, as required of all equipment near runways.

12) RELIABILITY AND MAINTENANCE

Reliability is not the major concern for the aircraft counter; accuracy is. It is expected that regular preventive maintenance would be required not more often than once every three months. It is also expected that this maintenance could be performed by technicians available at airports, as opposed to specially trained technicians.

13) DOCUMENTATION

All required documentation will be to accepted commercial standards, in contractor's format.

14) QUALIFICATION

DFS1000 shall be used as the guideline for qualifying the aircraft counter. Tests shall be designed to prove that the equipment meets the requirements of DFS1000, as applicable to the piece of equipment being tested.

15) TRAINING

No training is required for the prototype, since it is assumed that the contractor will be available for installation of the equipment.

5. SENSOR SELECTION

5.1 Sensors compared.

Having defined all requirements for the aircraft counter, the next phase was to select a sensor or sensor technologies that could be exploited to develop an aircraft counter. A number of potentially useful sensors and sensor technologies were considered in the study. These included

- Radar
- Acoustic
- passive infra-red
- microwave radiometers
- VLF loops
- magnetic anomaly detectors, and
- beam interception techniques.

The sensor technologies listed above are discussed in the feasibility study report. It was concluded that beam interception techniques, both optical and microwave, suffer from the disadvantage that their installation is difficult, needing towers very near the runway. Moreover, it would be possible to miss aircraft, no matter where they are placed. Magnetic anomaly detectors were discarded because the associated technology is new and expensive. Further, aircraft are not as ferrous as some of the ground traffic. Therefore, it was felt that they would make poor aircraft counters.

VLF loops and magnetic anomaly detectors suffer from the disadvantage that they cannot discriminate between airborne targets and ground vehicles. Moreover, VLF loops are big and expensive to install over runways. Therefore, for existing airports, VLF loops are not considered a viable option.

Passive infra-red and microwave radiometers were also considered. In both these, a sensor looking up perpendicular to the direction of landing or takeoff is a possibility. The length of time the aircraft is in the beam gives some indication of the size of the aircraft. However, detection is possible only if the aircraft intercepts the beam. Therefore, a fairly wide beam is required, and this beam will never be filled by the aircraft. In addition, the detection depends on the difference between the sky temperature with and without the aircraft. This is not a very

significant quantity, and detection is not easy. Hence, these are not suitable choices for an aircraft counter.

Various types of radars may be considered for aircraft counters. These include CW; FM-CW; pulsed; moving target indicator (MTI) and imaging radars. MTI and imaging radars were discarded early in the study because of their complexity, and because they are not suitable for this particular application. Pulsed radars would require very short pulses (50 nsec) in order to obtain the direction of motion of the target, which is required to get takeoff/landing discrimination. Such short pulses can be achieved, but the costs increase. Moreover, in order to detect targets at close range very fast T/R switches are required, making pulsed radars prohibitively expensive for aircraft counters. CW radars are simple police radars (Doppler). They do give information on direction of travel, and can be used for aircraft counters. They do not provide range information. Hence, such radars cannot give any form of classification of aircraft. If no other choice were available, Doppler or CW radars could be considered for aircraft counters. The FM-CW radar is a simple modification of a CW radar, which gives range information in addition to direction of motion. The range dependence of the radar return can be normalized, thus providing size (or radar cross-section) information. The added complexity over a simple Doppler radar is minimal, but the advantages are considerable. Hence, among all the radars considered, the FM-CW altimeter type radar stands out as a good sensor to use for the aircraft counter.

The last class of sensor considered was acoustic sensors. These may be divided into four classes. The first class of acoustic sensors are active. The second class are passive single channel (single microphone) systems. The third class consist of systems in which the signals from a number of microphones are combined in phase to accomplish beam-forming. The last class uses a number of passive microphones at different locations. The first and third classes were ruled out mainly because of cost. The second cannot give range or direction of motion, and does not have a high probability of detection. The last looks promising. A special example of this class is the concept of acoustic gates, discussed in detail in the previous reports.

5.2 Criteria for sensor selection.

In order to make the most judicious choice of sensor, a number of criteria were identified. These were to be used in the selection of sensor technology to be used in the remote aircraft counter. However, it was not possible to attach weights to each of the criteria, partly because of the wide variety of sensor configurations, and the difficulty in defining the relative

importance of the requirements at a wide variety of airports. It was, therefore, possible to use the criteria only as general guides in sensor selection. The criteria used are shown in Table 1 below.

Table 1 - Criteria for sensor selection.

1) HIGH PROBABILITY OF DETECTION IN 2 Km RANGE.
2) LOW FALSE ALARM RATE.
3) TAKEOFF/LANDING DISCRIMINATION.
4) SIZE (OR CLASS) DISCRIMINATION.
5) PASSIVE, OR LOW RADIATED POWER.
6) DISCRIMINATION AGAINST GROUND TRAFFIC.
7) DISCRIMINATION AGAINST AIRCRAFT ON OTHER RUNWAYS.
8) SIMPLICITY OF OPERATION.
9) EASE OF INSTALLATION.
10) SIMPLICITY IN SIGNAL PROCESSING.
11) RELIABILITY OF SENSOR, PROCESSING AND HARDWARE.
12) OPERATION IN DIFFERENT WEATHER AND ENVIRONMENTAL CONDITIONS.
13) LITTLE DEVELOPMENT RISK.
14) LOW COST.

5.3 Sensor recommendations.

A comparison of the various sensor technologies studied is summarized in Table 2. It is seen from the table that two sensors, the FM-CW radar and the passive acoustic, stand out as the most promising.

After the initial study of the sensors and sensor technologies available, it was recommended that the FM-CW radar, and the passive acoustic sensors be singled out for more detailed study. The results of this more detailed exploration are presented in the next few sections.

Table 2 - Comparison of Sensor Technologies.

1 = FM-CW RADAR
2 = PASSIVE ACOUSTIC
3 = PASSIVE INFRARED
4 = VLF
5 = MAGNETIC ANOMALY DETECTION
6 = BEAM-INTERCEPTION (OPTICAL AND MICROWAVE)

FEATURE	1	2	3	4	5	6
DETECTION	Y	Y	Y?	Y	Y?	Y
LOW F.A.R. (FALSE ALARM RATE)	Y	Y	Y?	N	N	Y?
TAKEOFF/LANDING DISC.	Y	Y	N	Y?	N	Y?
SIZE DISCRIMINATION	Y	N	N	N	N	Y?
VELOCITY ESTIMATION	N	Y	N	N	N	Y?
RANGE ESTIMATION	Y	Y	N	N	N	N
AIRCRAFT TYPE DISCRIMINATION	N	Y	N	N	N	N
SIMPLE OPERATION	Y	Y	Y	Y	N	Y
EASY INSTALLATION	Y	Y	Y?	N	Y	N
LOW HARDWARE RISK	Y	Y	Y	Y	N	Y
LOW SOFTWARE RISK	Y	Y	Y	Y	Y	Y
LOW COST	Y	Y	N	Y	N	Y?

6. SENSOR DESIGN

As a result of the earlier phases of this study, the conclusion was reached that both FM-CW radar and the acoustic gates concepts were promising candidates for the remote aircraft counter. Hence, a more detailed design was performed for these two sensors.

6.1 Design of FM-CW radar.

In order for a radar to detect aircraft taking off or landing, its beam must intersect all possible flight paths. An aircraft taking off usually starts from one end of the runway, lifting off as soon as it can. Lighter or smaller aircraft lift off earlier, while larger aircraft use more of the runway. After lift-off the aircraft may veer off to one side. Aircraft may land anywhere from near the end of the runway to half way along the runway. In order to intersect the extremes for both takeoff and landing, the preferred sites for the radar units are at both ends of the runway, with the antenna beams pointing above the runway surface with a narrow elevation beamwidth and a wider (typically 30 degree) azimuth fan beam. In order to comply with airport equipment height and size requirements, it may be necessary to place the radar antenna slightly to one side of the runway, rather than down the centre line. The placement of the radars, as shown in Figure 1, has the advantage of not intersecting ground vehicles due to the vertical tilt of the elevation beam.

6.1.1 Radar Type.

In order to detect airborne targets at close range, a radar must use either ultra-short pulses or some form of waveform modulation which can infer a target return in the presence of transmitter feedthrough. Ultra short pulse radars are complicated and very expensive. On the other hand, FM-CW altimeter type radars are in common use, and less expensive. They infer the presence of a target, and its range, by linearly ramping its transmitted feedthrough which can be used for detection purposes. In addition, the frequency of the offset, as well as its amplitude, can be used to determine range and target size.

A block diagram of an FM-CW radar which can detect airborne targets; sort them according to size; and discriminate between takeoff and landing operations, is shown in Figure 2. Here, the sawtooth generator provides a tuning voltage to the VCO, which linearly ramps up and down in frequency. The signal is passed via the circulator to the antenna for transmission, and also to the LO port of the down-conversion mixers. The radiated signal, reflected off the airborne target, is received by the antenna, and is passed via the circulator to the RF input of the mixer.

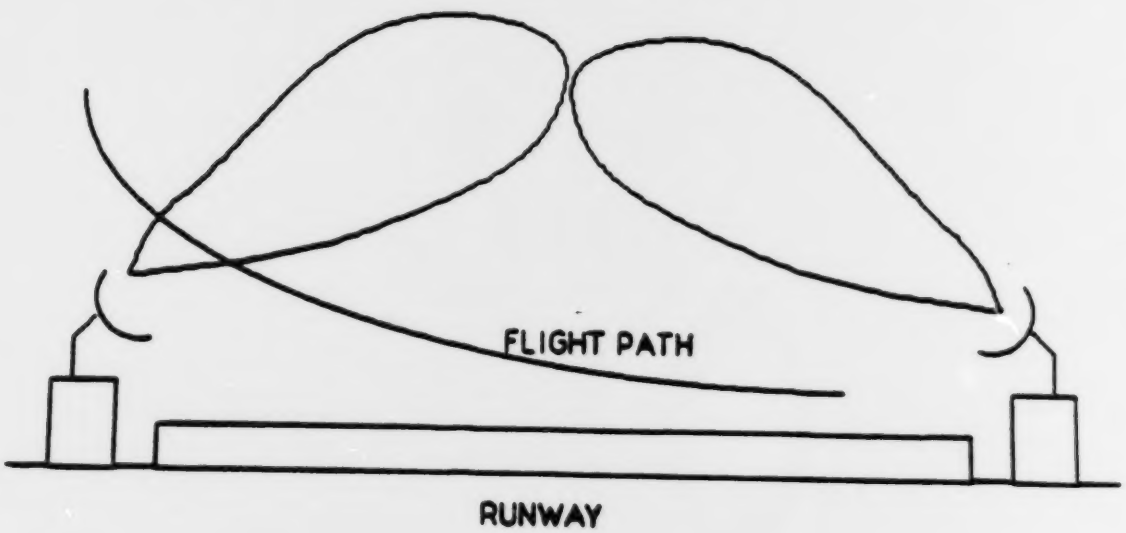


Figure 1 - Radar Set Placement at Ends of a Runway.

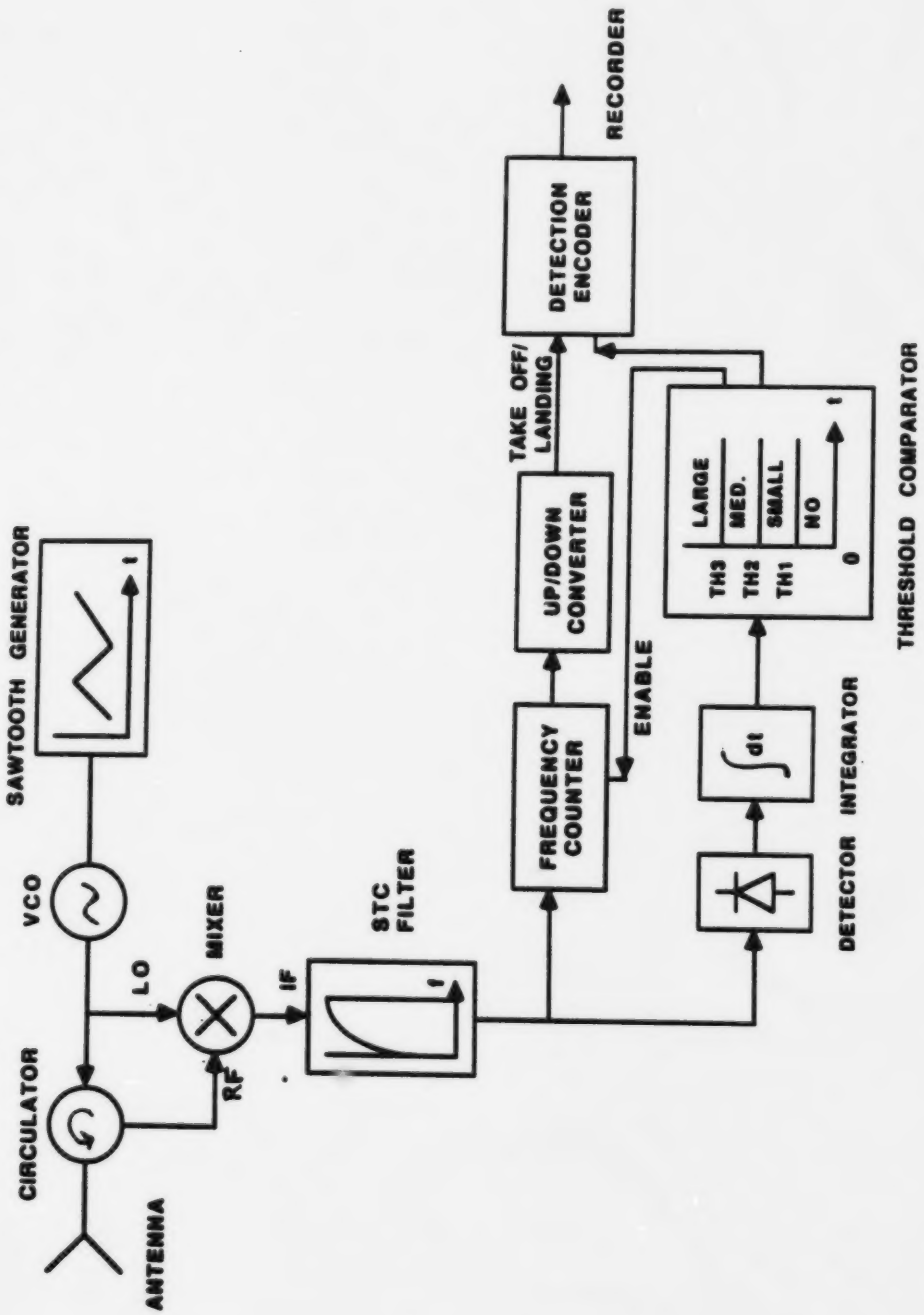


Figure 2 - Block Diagram of FM-CW Radar

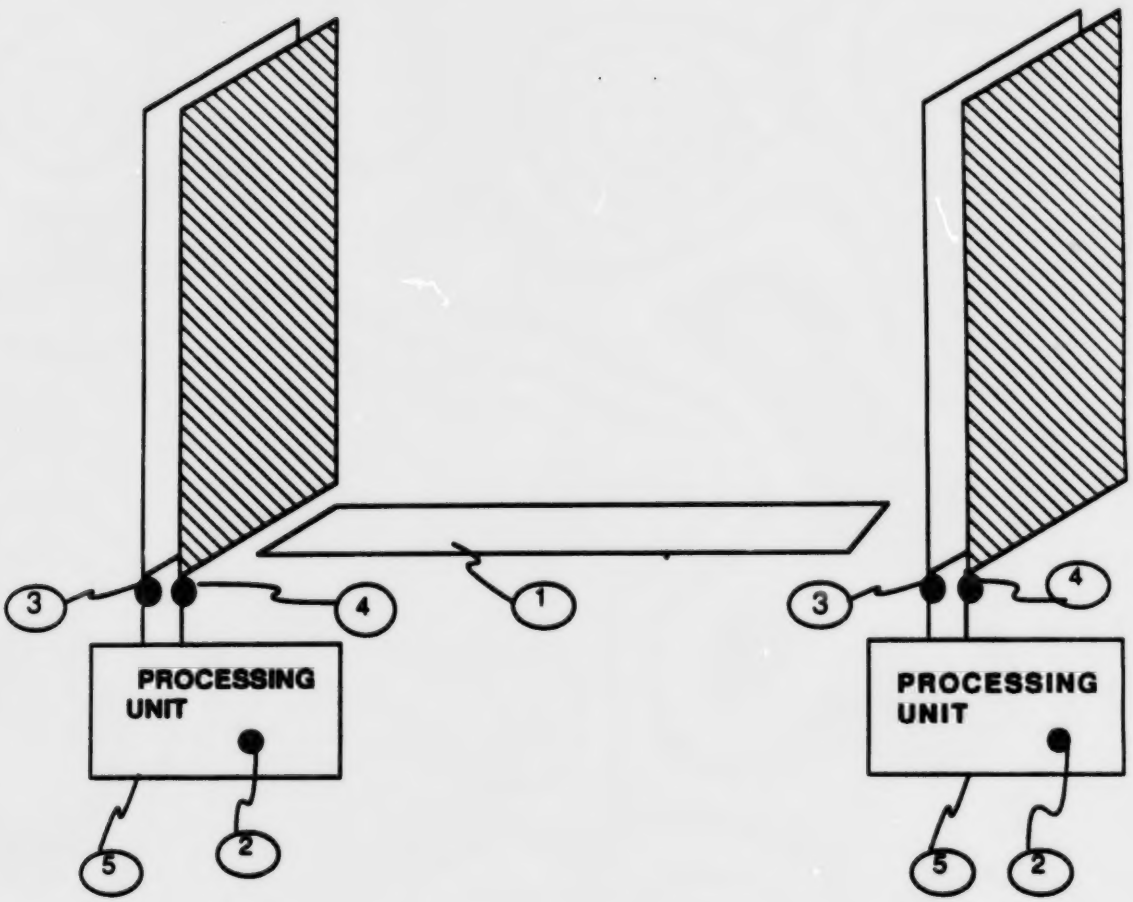
The output IF of the mixer is at a frequency corresponding to the range of the target, and has an amplitude dependent on the range and the radar cross-section of the target. The range dependence of the IF signal amplitude is removed by the STC filter, leaving only the target cross-section dependence. The detector provides a baseband voltage proportional to this signal power. Fluctuations in the target cross-section due to short-term changes in the aspect of the target are averaged out using the long-time-constant integrator. The averaged baseband voltage is then applied to a multiple threshold comparator circuit, in order to register a target detection, and to classify the target according to size. The detection of a target also enables the frequency counter, which measures the frequency of the IF signal emerging from the STC filter. This frequency is measured regularly over a period of a few seconds, and an increase or decrease is registered on the up/down counter. Since the frequency of the IF signal is proportional to the range, the output of the up/down counter indicates whether a target is approaching or receding from the radar (i.e. taking off or landing). Thus the FM-CW radar is a simple sensor for detecting aircraft operations.

6.2 Design of Acoustic Sensor.

The principle of the acoustic sensor for the aircraft counter was presented in the "Feasibility Study for the Remote Aircraft Counter" report. It is proposed that acoustic gates, capable of characterizing and counting aircraft passing through them, be established at appropriate positions along the runway.

Figure 3 outlines the principle of operation of the acoustic gates. The noise radiated by passing aircraft is received by two directional microphones, spatially separated along the runway. This allows determination of the direction of motion of the aircraft, as well as other parameters, with very simple signal processing. Basically, the acoustic power received by each sensor is analyzed in two or three frequency bands. Any peaks detected in these bands are parametrized into their level, duration, signal-to-background ratio, and position of the peak in frequency. When acceptable values of these parameters are observed, the times of occurrence of the peaks in adjacent sensors are compared to determine the direction and speed of motion. The amplitude of the signal gives a rough classification of the aircraft. The following sections describe a possible implementation of acoustic gates.The numerical values of parameters such as frequencies, bandwidths, and the number of channels per microphone may be refined as a result of the prototype evaluation. The issues of discrimination against ground traffic, self-test capabilities, and expected performance were also addressed, the results of which are contained in the feasibility report.

The design presented is based on field measurements carried



Geometry : (1) Runway.
(2) Processing units.
(3), (4) Planes of symmetry of the response of the acoustic sensors.
(5) Optional Accelerometers.

Figure 3 - Geometry of Acoustic Gates.

out recently at Ottawa International and Carp airports.

6.2.1 Field measurements of takeoff and landing noise

Measurements were carried out at Ottawa International Airport on August 7, 1987, for landings of light, two-seater training aircraft (Cessna 150 type) and at Carp airport for the takeoffs of similar aircraft. The main concern prior to the tests was that landings under reduced power would not be noisy enough to permit detection.

In these tests, the microphones were positioned at the touch-down and takeoff ends of the runway respectively. Results obtained confirm that light aircraft can be counted acoustically at takeoff and landing. The recordings are illustrated in Figures 4,5 and 6, which are typical of the noise recordings observed. Representative background noise samples were also recorded from road traffic noise, small aircraft engine tests, business-jet taxiing and close overflights. In most cases, the noise levels produced at frequencies above one to a few kHz would not have prevented the proper functioning of acoustic gates.

The sensor architecture and processing required for the acoustic gates is described in detail in the design document. The elements of the processing are shown in Figure 7.

In addition to this, the document also describes methods for discriminating against ground traffic; the expected accuracy; and self-test features.

If it is desired to detect only aircraft taking off on a runway, as opposed to aircraft taking off and landing, a considerable simplification of the sensor system could be achieved.In fact, since takeoffs are some 20 to 30 dB noisier than landings for light aircraft, they would by reliably detected in just one frequency band. Further, discrimination against ground traffic could be readily achieved on the basis of noise level alone.

Based on available experimental data, and the system considerations discussed above, it is believed that acoustic gates constitute a reliable, cost-effective solution to the remote aircraft counter sensor requirement.

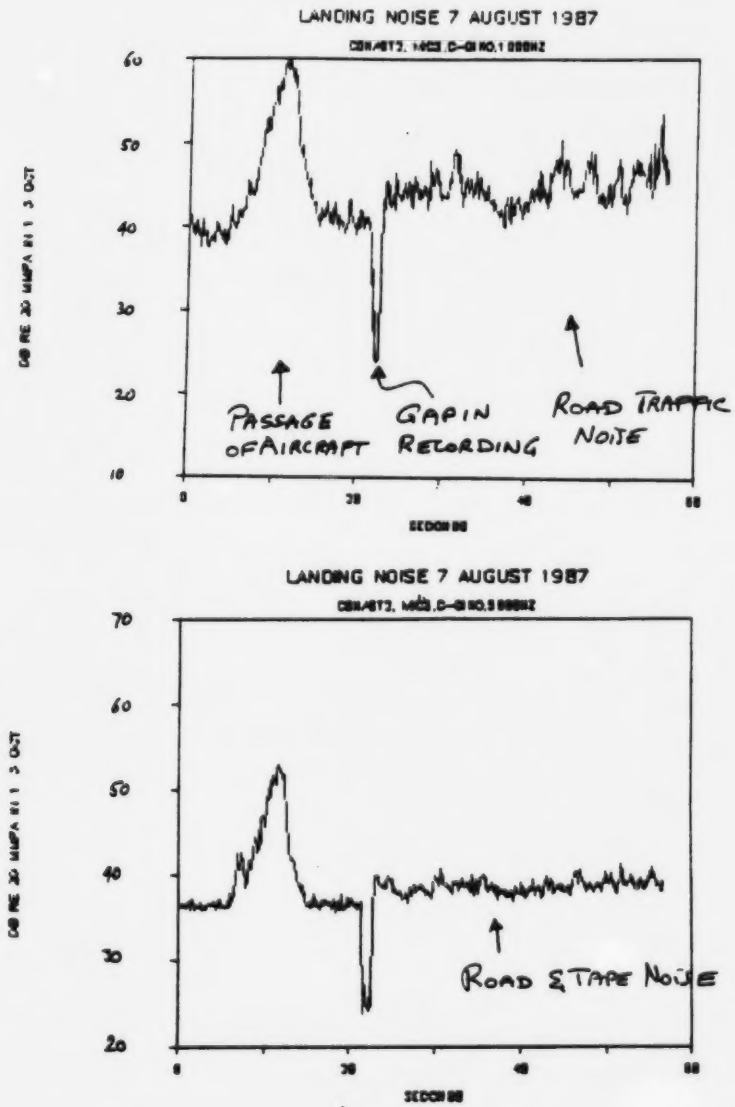


Figure 4 - Measured Landing Noise at 1000 and 5000 Hz.

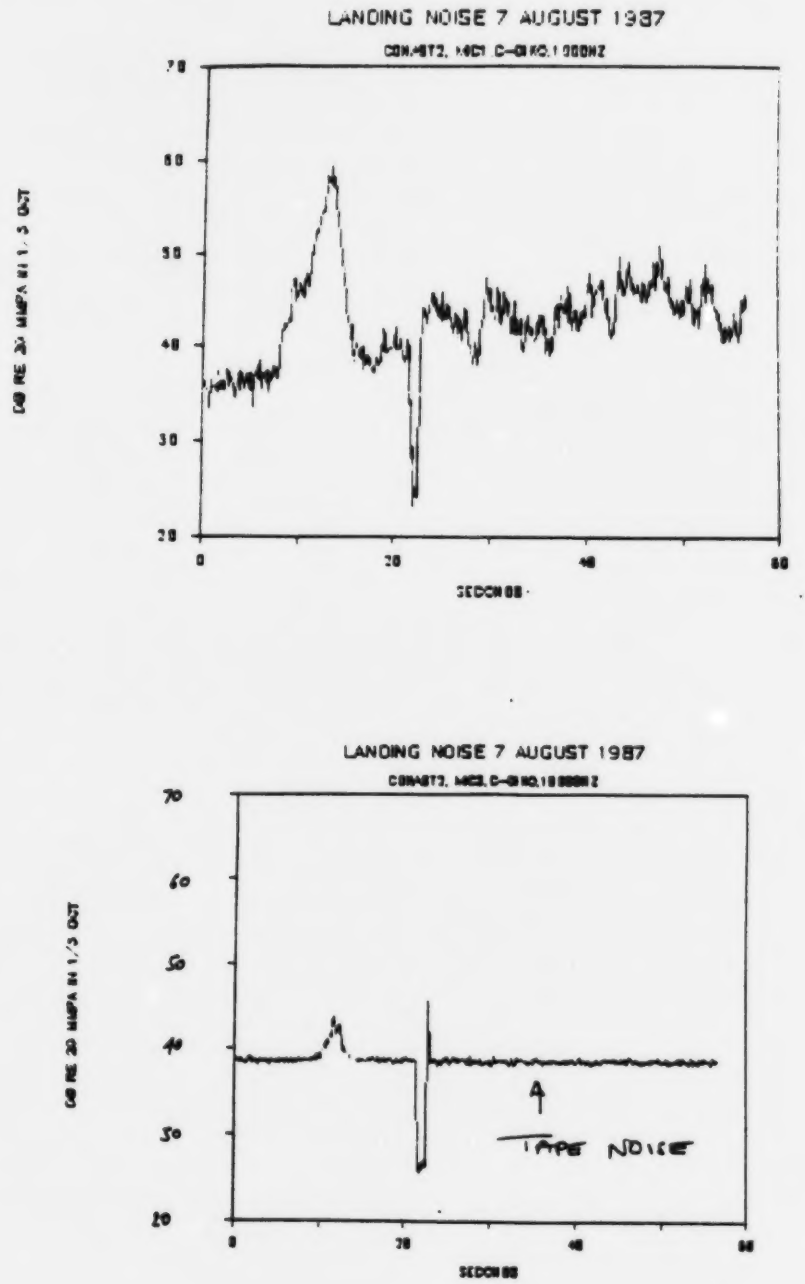


Figure 5 - Landing Noise at 1000 and 10000 Hz.

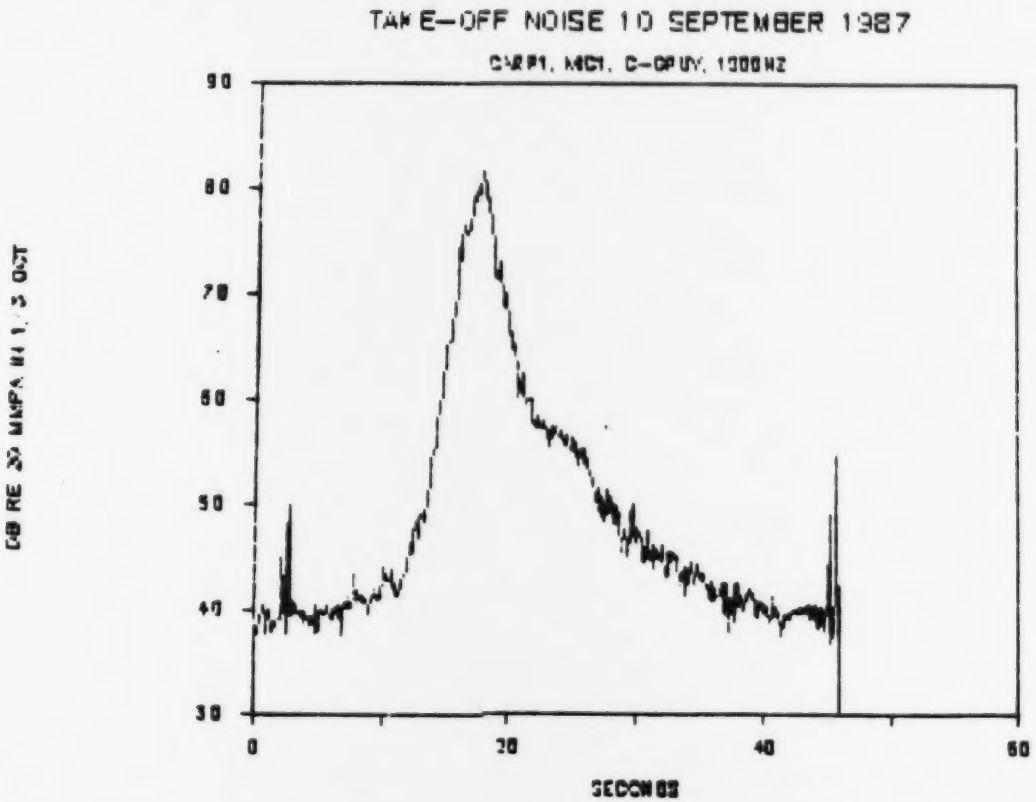


Figure 6 - Takeoff Noise at 1000 Hz.

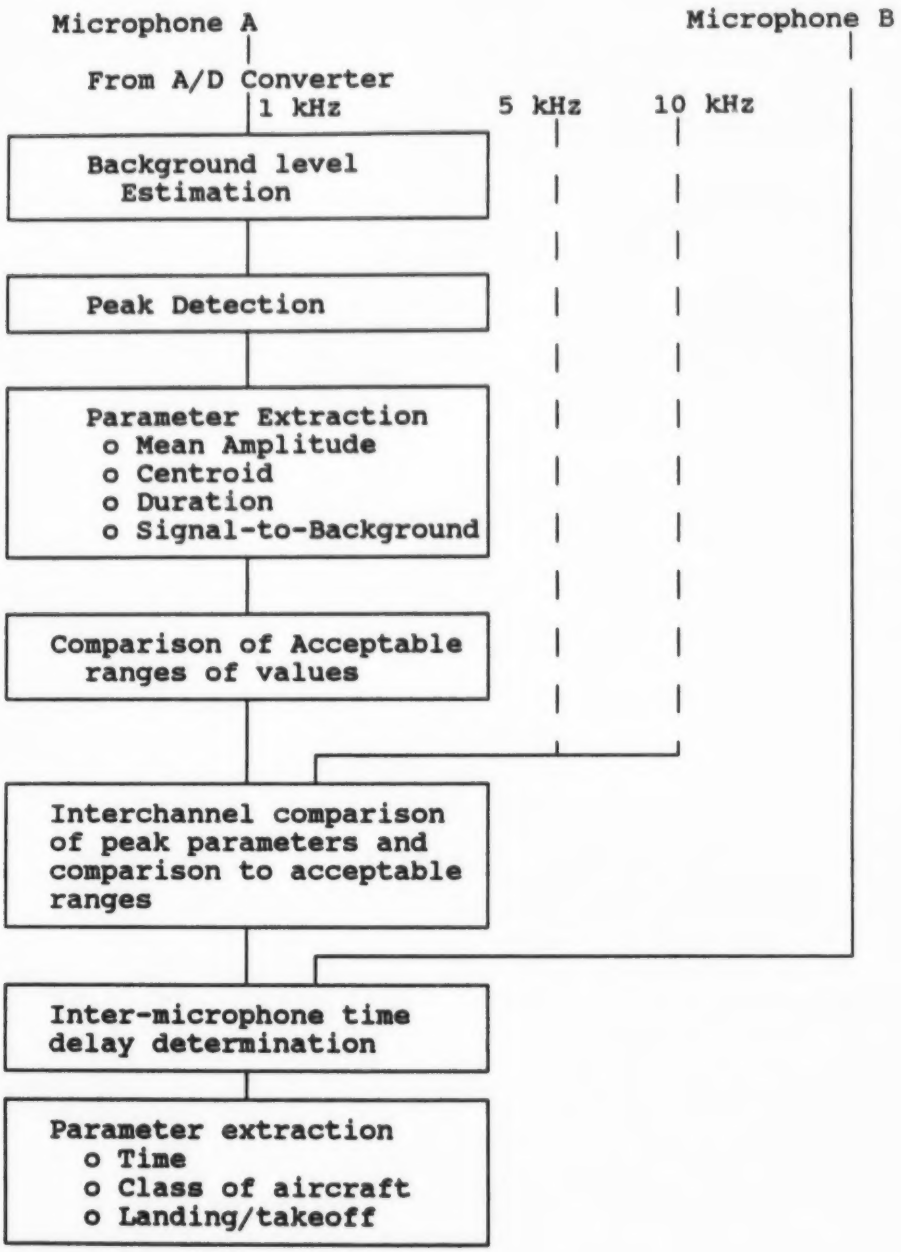


Figure 7 - Flow chart of the digital processing.

7. SYSTEM DESIGN

System trade-offs were performed for the configuration of sensors and the central processor, along with communications interfaces and storage. These are summarized in this section. Details are available in the prototype design document.

7.1 Sensor Configuration

Each aircraft counter may be configured with one or more sensors. It is not advantageous to use two sensors of the same type, say the radar, although this does provide dual redundancy. However, using two significantly different sensors can improve system performance. For example, the acoustic and radar sensors rely on totally different sensing elements. Consider the case where the noise generated by a landing aircraft is drowned out by other noise sources, like heavy rainfall or the noise of a jet engine being revved up. In such a circumstance, the radar will still detect the incoming aircraft. It is also possible that the acoustic sensor may miss an aircraft that veers off the centre line too rapidly after takeoff. This would still be detected by the radar. On the other hand, it is possible for an aircraft to be missed by the radar, if its flight trajectory is such that it crosses the radar beam in too short a time, although the placement of the radar is designed to minimize this effect. In such a case, the acoustic sensor would register the event, while the radar does not. Thus, using two sensors, it is possible to increase the accuracy of the count. However, a dual sensor system used this way will not eliminate false alarms, because there is no way of deciding if one sensor missed detection or the other generated a false alarm. One could consider a third sensor to settle this, but that would probably be overdesign for the aircraft counter.

Based on the above discussion, it is recommended that the aircraft counter be implemented with two sensors, especially for the evaluation phase, since the incremental cost for producing a dual sensor system is not high. It may turn out during evaluation that one of the sensors is good enough to meet the requirements for the aircraft counter, in which case a single sensor could be used in the production model.

7.2 System Configuration

Having chosen the sensor configuration, there are a number of ways in which a system of aircraft counters can be implemented at an airport. These fall into two classes, one in which independent aircraft counters are placed at the ends of runways, and the other in which all counters are connected to and controlled by one central processor. The main disadvantage with the second alternative is that communications links are required from the ends of the runways to a central location in the airport

complex. The problem of communications links was studied. This is detailed in the design document. The conclusion reached was that the best method would be to use twisted pair cables for the links, and that these would best be installed using existing cable ducts at the airports. However, even this is not a very attractive alternative. The recommended configuration (class of independent counters) for the aircraft counter is shown in Figure 8.

A) The recommended configuration includes :

i) A dual sensor (radar and acoustic)
ii) 128 KBytes of local storage
iii) Operation to - 40°C with batteries, and to -55°C with AC power
iv) Access to detector via a plug-in cable using a portable "laptop" computer.
v) Central storage consists of a 10 MByte hard disk supplemented with 3½" floppy disks.
vi) Built-in self-test at receiver, activated manually or automatically every 24 hours.

Options include :
i) Battery to -40°C
ii) Battery to -55°C
iii) sensor self-test

B) The alternate configuration (central processor class), shown in Figure 9, is identical to the above, except that

- no local storage is provided
- a serial data link 3-wire cable to a centrally located location is needed.
- a centrally located computer with a hard disk and floppy back-up is used
- a polling unit to poll each sensor (at least once every 20 seconds for each end of every runway) for detection status.
- Options include substitution of a telephone line or radio link for the cable, which will require the addition of two modems.

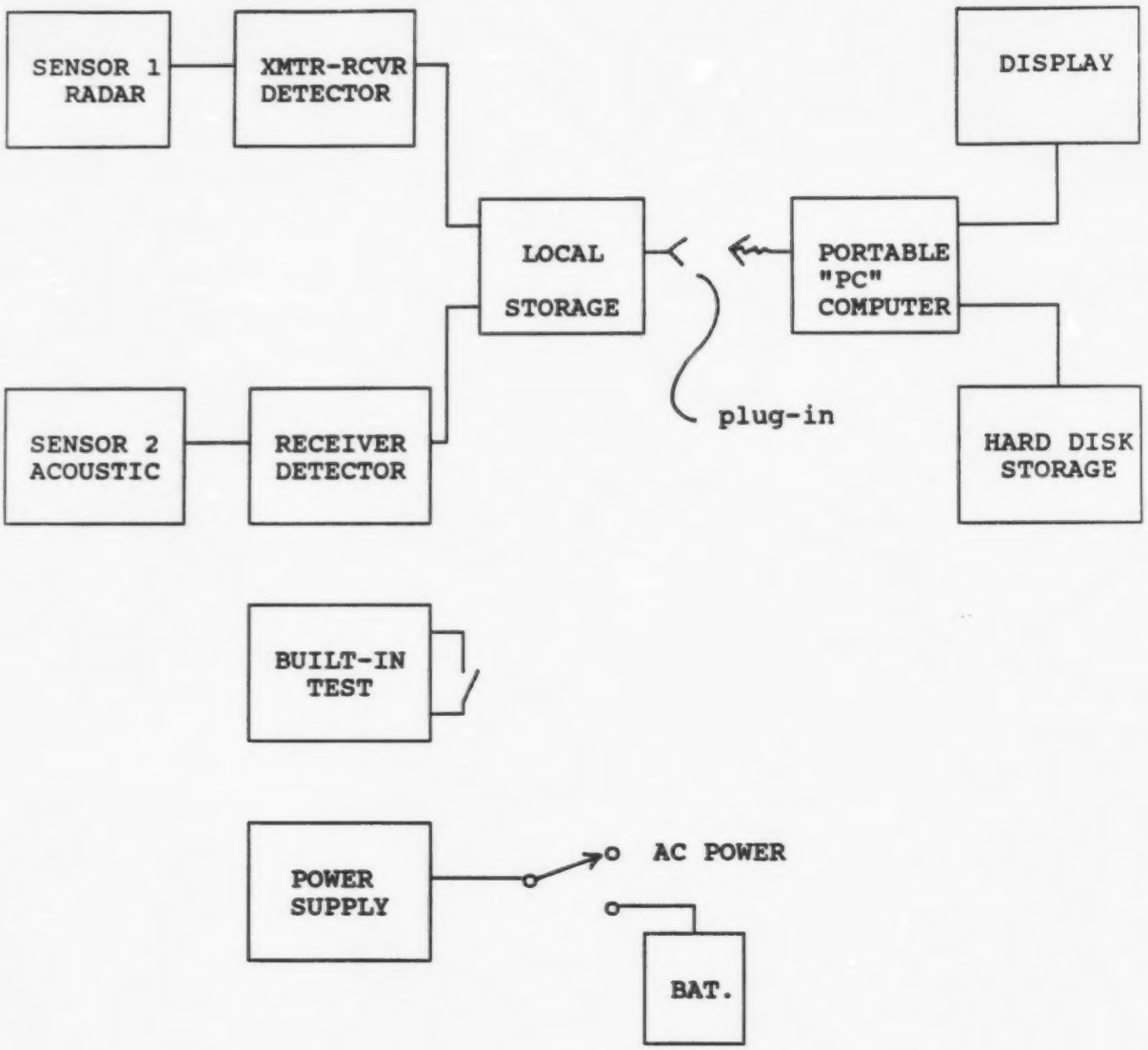


Figure 8 - Block Diagram of Recommended Configuration

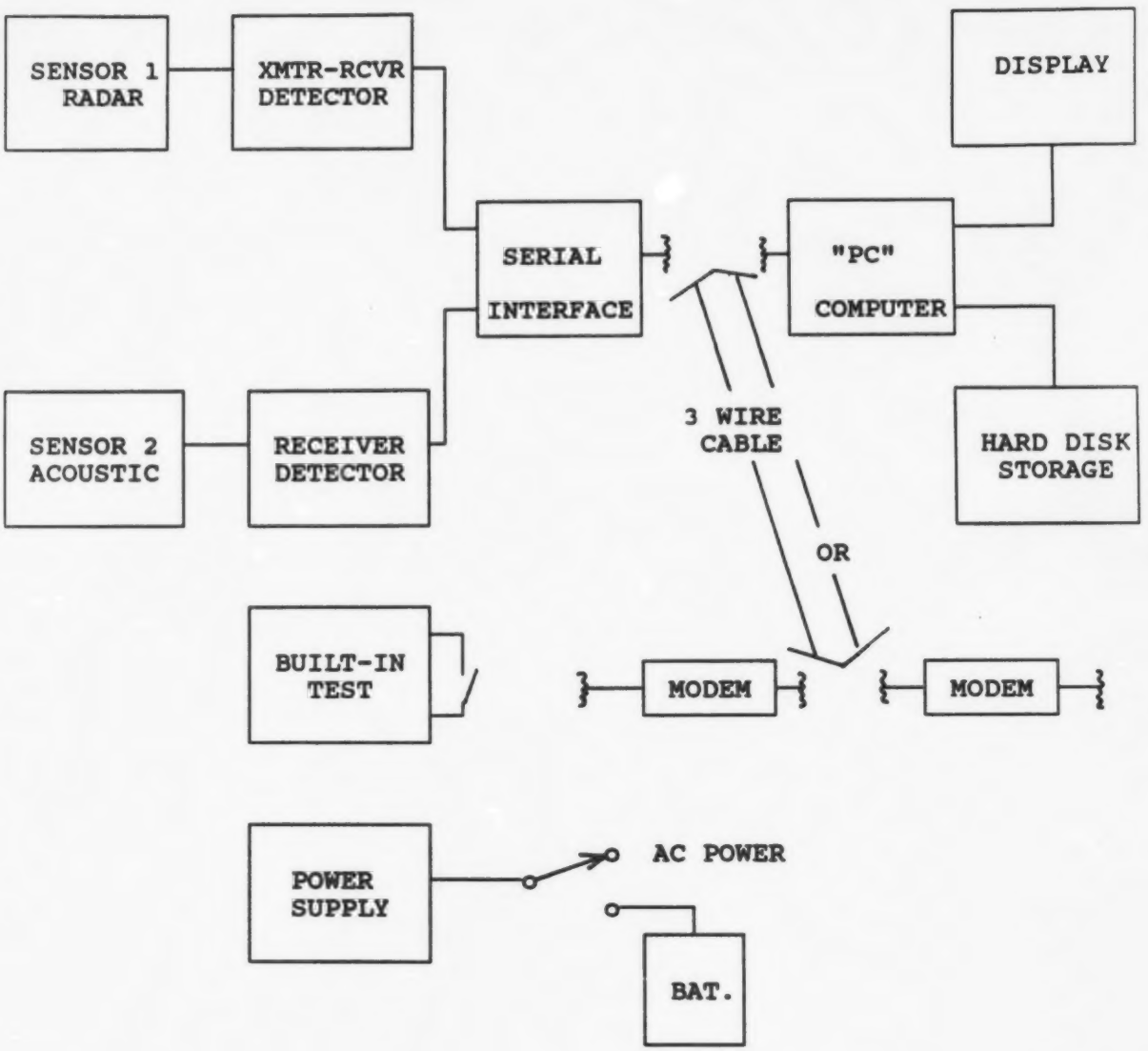


Figure 9 - Alternate Configuration.

8. PROTOTYPE PRODUCTION PLAN

The plan for prototype development plan consists of two segments. The first part is the design and building of a prototype. The second is the evaluation of the prototype. Both are discussed below.

8.1 Plan for Prototype Development.

Since the proposed aircraft counter is not an off-the-shelf item, it is necessary to construct a prototype, conduct a field evaluation of the prototype, and then produce a version suitable for manufacture in larger quantities. This section describes the prototype system.

The radar transceiver consists of a transmitter, triangle waveform generator, antenna, STC filter, detector, frequency slope detector, and a threshold unit.

a) Transmitter - low power (200 mw), variable frequency oscillator at 1.9 GHz centre frequency, triangle waveform modulated at 750 Hz with a deviation of ± 100 MHz, nominally linear.
b) Triangle waveform generator - with 750 Hz repetition rate.
c) Antenna - parabolic dish (0.5 m diameter) with feed, bandpass filter and circulator.
d) Receiver - low noise pre-amplifier.
e) STC filter - filter bandwidth of 2 MHz, with an STC filter based on frequency slope equalizer, and a detector with 30 dB dynamic range.
f) Threshold - three threshold settings to define different aircraft classes.
g) Frequency slope detector - the rate of change of frequency determines the direction of motion of the target.

The transmitter, circulator, filter and antenna are available off-the-shelf. The design of the triangle waveform generator, receiver, STC filter and threshold units will be based on wide-band operational amplifiers, while the frequency slope detector will be implemented in digital CMOS.

The acoustic subsystem consists of microphones, pre-amplifiers, bandpass filters, detector, digitizer, low pass filter, centroid calculator, and threshold units.

a) Microphones - outdoor, preferably directional, 1 to 10 kHz.
b) Pre-amplifier - low noise audio.

c) Bandpass filter - 2 sets of three filters, centred at 1, 5 and 10 kHz.
d) Detector - six wide-dynamic-range (60 dB) detectors.
e) Digitizer - 12-bit digitizer, 120 Hz rate, with 6 channel multiplexer.
f) Lowpass filter - time constant of 0.5 second, plus a background noise filter with a 2 hour time constant.
g) Centroid calculator - calculates the centroid of the received signal above a pre-set threshold.
h) Threshold unit - used to define aircraft class from the amplitude of received signal in different frequency bands.

The microphone will be selected for ruggedness and directionality from an assortment of off-the-shelf microphones. Preamplifiers, filters and detectors can be implemented using analog circuitry. A digitizer is proposed primarily to ensure that the long time-constant filter can be implemented digitally to ensure stability over the required temperature range.

The local storage subsystem consists of a memory unit, clock circuitry, data read and write circuitry, and a built-in test capability.

a) Clock - a 10 second clock and a 24-bit counter will be used to time from 10 seconds to 194 days.
b) Data loading - detection of a target will enable the contents of the clock register, the target class, the target direction, and the result of the built-in test, to be transferred to the memory.
c) Memory - 128 KBytes of memory.
d) Data read - external command allows data to be read from the memory through a UART and an RS232 line.
e) Built-in Test - triggered manually, or once every 24 hours, will introduce a simulated target into the receivers.

For cost estimation, it is assumed that an off-the-shelf computer will be selected (such as the PROLOG STD bus product, based on a CMOS version of the 8085 or 8088). This unit, together with 128 Kbytes of memory, will perform over the -40^{o}C to +70^{o}C temperature range.

The subsystems can be mounted in a STD bus rack with wirewrap and PCB cards for the analog and digital interface circuits. An enclosure of approximately 20x20x30 cm could be used to hold the unit, with the parabolic dish antenna and microphones mounted outside the box.

8.2 Plan for Prototype Evaluation.

The system shall be subjected to an evaluation test at a typical airport over a 6-12 month period which includes June and January. It is proposed that each evaluation be conducted over a 1 or 2 week period at a reasonably busy airport such as Toronto, followed by an

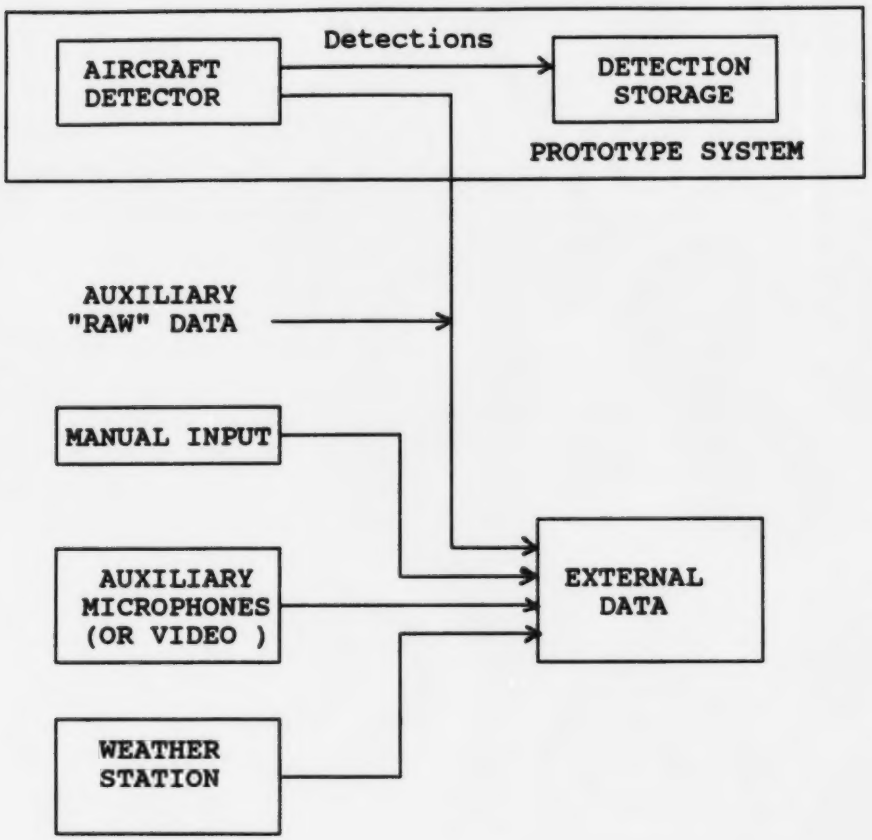
analysis of the operational performance.

In order to properly assess the performance, it will be necessary to carefully document all aircraft landings and takeoffs at the runway throughout the assessment period. This could be done by hiring sufficient personnel to record all factors (i.e. the weather conditions , type of aircraft and the time). However, an automatic recording device could be used instead to provide this, and additional data useful in identifying false targets and in optimizing threshold settings.

8.2.1 Automatic Recording Device.

A block diagram showing the evaluation test equipment connection is shown in Figure 10. It is proposed that the monitor system be mounted in a trailer (with internal heating and cooling) located near the aircraft counter. As a consequence, the tape recorder could be driven by a small computer, such as an IBM PC, equipped with an A/D converter, with results being stored on a hard disk. The tape recorder should be set at a low threshold, so that all operations, and conditions during false alarms, are recorded. The raw sensor data from both sensors would be digitized, and upon detection of a target, 15 seconds of data before the event plus 15 seconds of data after the event would be recorded.

It would also be valuable to include an audio tape recorder to record the acoustic signature of the target during the same time period. An optical video recorder (camcorder) would also be a valuable addition.



FEATURES OF TEST APPROACH

- DATA RECORDING
  - ± 15 SECONDS RECORDING ON DETECTION
  - LOW THRESHOLD SELECTABLE
  - BASED ON "PC" + AUDIO TAPE RECORDER/ VIDEO
  - TRAILER-MOUNTED OR CABLE TO CENTRAL LOCATION
- DATA ANALYSIS
- TEST REPORT

Figure 10 - Field Evaluation - Test Approach.

At the end of the test period, the recorded data must be analyzed, correlated with the control tower information, and statistics compiled for:

i) aircraft counted correctly
ii) false alarms
iii) missed aircraft operations
iv) landing/takeoff discrimination
v) accuracy of aircraft classification.

If the performance was poorer than expected, fine adjustments to the threshold could be made prior to the start of the second test period. However, such changes are not recommended, unless absolutely essential.

The cost estimate is based on conducting 10 such tests, each 14 days long, over a 7 month period. Moving the sensor to a second site for some of the tests is considered optional, and not included in the costs.

8.3 Cost Estimates.

For costing purposes, it is proposed that the recommended configuration be used as a costing base-line. The alternate configuration differs from this in that the costs of the communications link will be an added expense, as will the cost of developing a central archival system for all sensors at the airport.

Costs for prototype production are broken down into both single and dual sensor systems. The costs for a prototype consisting of just a radar are shown in Table 3; for an acoustic sensor in Table 4; and for the dual sensor system in Table 5. The costs, including those for evaluation, are summarized in Table 6.

The costs of each of the three major tasks is estimated by producing a Work Breakdown Structure, shown in Figure 11, where each task is further broken down into sub-tasks. The total cost is then summed to total labour hours, and total direct charge dollars. An average estimated labour rate of $80/hr is used, together with a direct charge mark-up of 35%. (These rates are estimates only. DSS may be able to provide industry average rates). A schedule is shown in Figure 12.

The costs provided in this section are for budgetary purposes only. This is not an official CAL proposal. CAL will be happy to provide a full proposal on request.

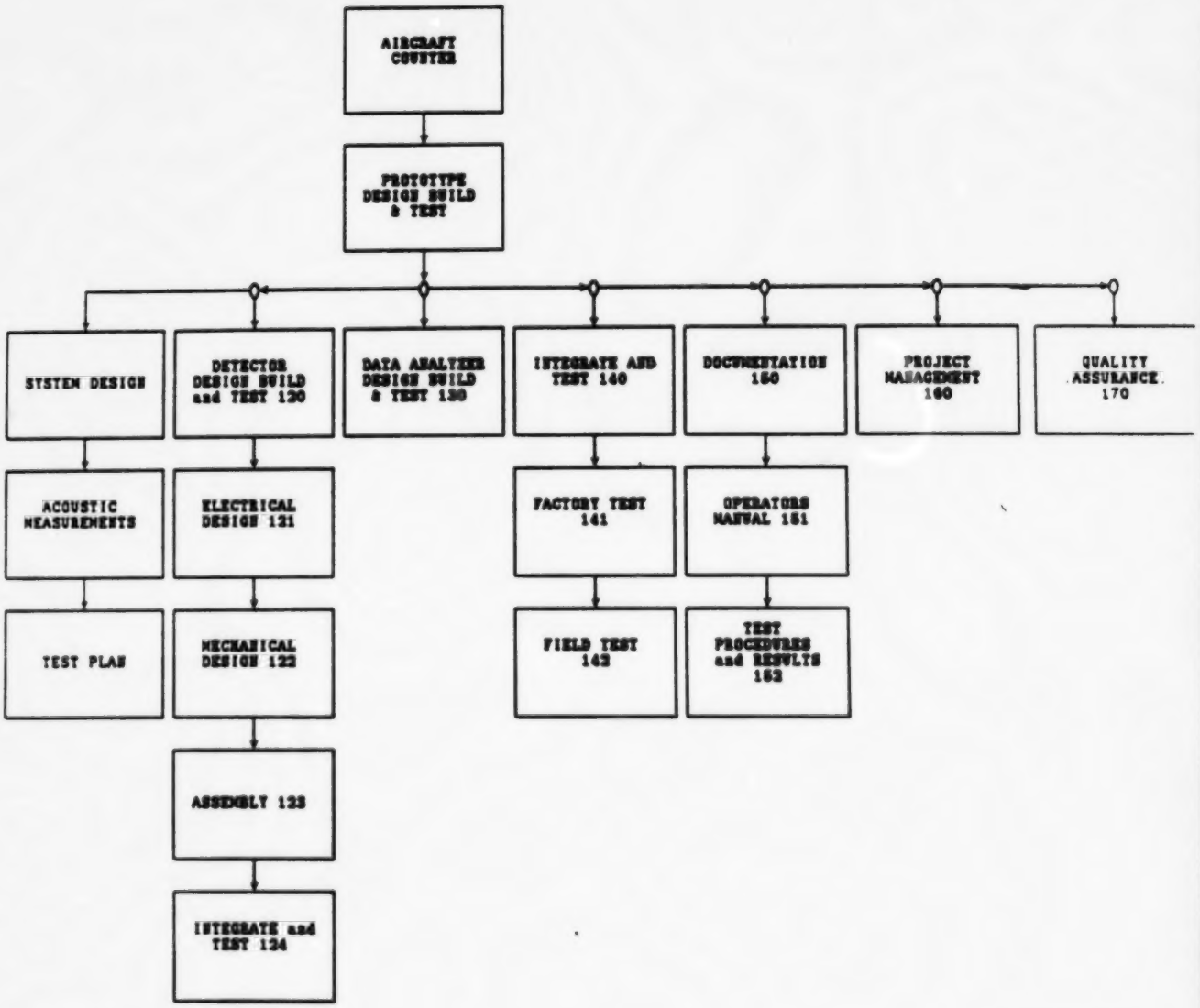


Figure 11 Work Breakdown Structure

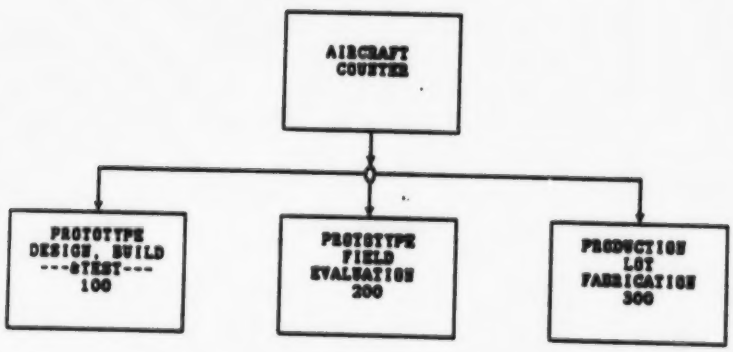


Figure 11 Work Breakdown Structure (Continued)

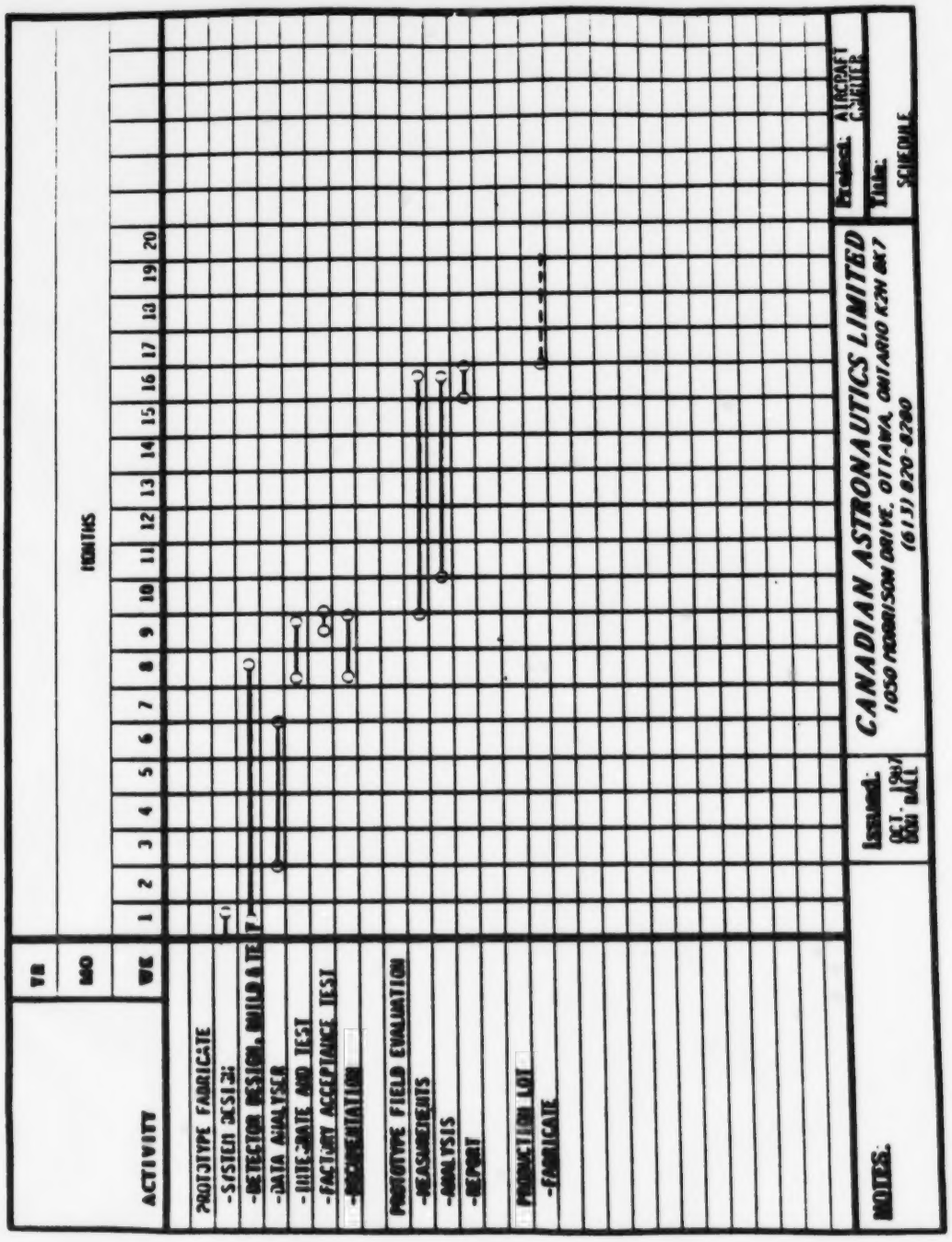


Figure 12 Schedule

Table 3 - Cost of system with radar sensor.

AIRCRAFT COUNTER COST ESTIMATE -PROTOTYPE-RADAR ONLY

WP	TASK	ENG	THL	TCN	DFT	CLR	LABOR	MATLS	MISC	DIRECT
110	SYSTEM DESIGN						0			0
	-FUNCTIONAL REQTS SPE	65				10	75			0
	-INSTALLATION PLAN	15				5	20			0
	-DESIGN REVIEW	15				5	20			0
111	ACOUSTIC MEASUREMENTS						0			0
	-MEAS'TS ANALYLSIS						0			0
112	TEST PLAN	15					15			0
120	DETECTOR DSGN,BUILD & TEST						0			0
	-SUBSYSTEM SPEC'S	25					25			0
121	ELECTRICAL DESIGN						0			0
	-ANALOG SUBSYSTEM	225			150		375			0
	-DIGITAL SUBSYSTEM	175			250		425			0
	-SOFTWARE	150					150			0
122	MECHANICAL DESIGN						0			0
	-SENSOR,DETECTOR PKG	120			175		295			0
123	ASSEMBLY		25	100			125	15000		15000
124	INTEGRATE AND TEST						0		1000	1000
	-INTEGRATE	80	40	25			145			0
	-TEST	10	35	35			80			0
130	DATA ANALYZER						0			0
	-DESIGN,BUILD &TEST	40	40		50		130	10000		10000
	-SOFTWARE	150					150			0
140	INTEGRATE & TEST	130	130	40			300		1000	1000
141	FACTORY TEST						0		500	500
	-PERFORMANCE	15	40		40		95			0
	-TEMPERATURE		40				40			0
142	FIELD DEMO		40				40		500	500
150	DOCUMENTATION						0			0
151	OPERATORS MANUAL	35	35			10	80			0
152	TEST PROCED./RESULTS	35	35			10	80			0
160	PROJECT MANAGEMENT	220				40	260			0
170	QUALITY ASSURANCE	50		125			175			0
		1570	460	325	665	80	3100	25000	3000	28000

LABOR TOTAL	3100
DIRECT TOTAL	28000

Table 4 - Cost of system with acoustic sensor.

AIRCRAFT COUNTER COST ESTIMATE -PROTOTYPE-ACOUSTIC ONLY

WP	TASK	ENG	THL	TCN	DFT	CLR	LABOR	MATLS	MISC	DIRECT
110	SYSTEM DESIGN						0			0
	-FUNCTIONAL REQTS SPE	75				10	85			0
	-INSTALLATION PLAN	15				5	20			0
	-DESIGN REVIEW	15				5	20			0
111	ACOUSTIC MEASUREMENTS	5		30			35	3000	1000	4000
	-MEAS'TS ANALYSIS	10		30		10	50			0
112	TEST PLAN	15					15			0
120	DETECTOR DSGN,BUILD & TEST						0			0
	-SUBSYSTEM SPEC'S	30					30			0
121	ELECTRICAL DESIGN						0			0
	-ANALOG SUBSYSTEM	150			150		300			0
	-DIGITAL SUBSYSTEM	200			250		450			0
	-SOFTWARE	250					250			0
122	MECHANICAL DESIGN						0			0
	-SENSOR,DETECTOR PKG	120			175		295			0
123	ASSEMBLY		25	90			115	14000		14000
124	INTEGRATE AND TEST						0		1000	1000
	-INTEGRATE	80	40	25			145			0
	-TEST	10	25	25			60			0
130	DATA ANALYZER						0			0
	-DESIGN,BUILD &TEST	40	40		50		130	10000		10000
	-SOFTWARE	150					150			0
140	INTEGRATE & TEST	130	130	40			300		1000	1000
141	FACTORY TEST						0		500	500
	-PERFORMANCE	15	40		40		95			0
	-TEMPERATURE		40				40			0
142	FIELD DEMO		40				40		500	500
150	DOCUMENTATION						0			0
151	OPERATORS MANUAL	35	35			10	80			0
152	TEST PROCED./RESULTS	35	35			10	80			0
160	PROJECT MANAGEMENT	220				40	260			0
170	QUALITY ASSURANCE	50		125			175			0
		1650	450	365	665	90	3220	27000	4000	31000

LABOR TOTAL 3220
DIRECT TOTAL 31000

Table 5 - Cost of system with dual sensors.

AIRCRAFT COUNTER COST ESTIMATE -PROTOTYPE-COMBINED

WP	TASK	ENG	THL	TCN	DFT	CLR	LABOR	MATLS	MISC	DIRECT
110	SYSTEM DESIGN						0			0
	-FUNCTIONAL REQTS SPEC	75				10	85			0
	-INSTALLATION PLAN	15				5	20			0
	-DESIGN REVIEW	15				5	20			0
111	ACOUSTIC MEASUREMENTS	5		30			35	3000	1000	4000
	-MEAS'TS ANALYSIS	10		30		10	50			0
112	TEST PLAN	25					25			0
120	DETECTOR DSGN,BUILD & TEST						0			0
	-SUBSYSTEM SPEC'S	30					30			0
121	ELECTRICAL DESIGN						0			0
	-ANALOG SUBSYSTEM	350			300		650			0
	-DIGITAL SUBSYSTEM	200			250		450			0
	-SOFTWARE	325					325			0
122	MECHANICAL DESIGN						0			0
	-SENSOR,DETECTOR PKG	150			200		350			0
123	ASSEMBLY		30	120			150	20000		20000
124	INTEGRATE AND TEST						0		1000	1000
	-INTEGRATE	100	50	25			175			0
	-TEST	10	40	40			90			0
130	DATA ANALYZER						0			0
	-DESIGN,BUILD &TEST	40	40		50		130	10000		10000
	-SOFTWARE	150					150			0
140	INTEGRATE & TEST	150	150	50			350		1000	1000
141	FACTORY TEST						0		500	500
	-PERFORMANCE	15	40		40		95			0
	-TEMPERATURE		40				40			0
142	FIELD DEMO		40				40		500	500
150	DOCUMENTATION						0			0
151	OPERATORS MANUAL	40	40			10	90			0
152	TEST PROCED./RESULTS	40	40			10	90			0
160	PROJECT MANAGEMENT	250				50	300			0
170	QUALITY ASSURANCE	50		150			200			0
		2045	510	445	840	100	3940	33000	4000	37000

LABOR TOTAL 3940 hrs
DIRECT TOTAL 37000 $

Table 6 - Cost Summary.

1.	System with only radar sensor	$ 285,800.00
2.	System with only acoustic sensor	$ 299,450.00
3.	System with dual sensors	$ 365,150.00
4.	Evaluation (830 hours + $22,000 direct)	$ 96,100.00

9. RECOMMENDATIONS FOR A REMOTE AIRCRAFT COUNTER

Previous sections of this document, and the "Feasibility Study for the Remote Aircraft Counter", an earlier document produced in this study, studied the operational and other requirements for the aircraft counter, as well as a number of candidate sensors and technologies that may be used for accurate counting of aircraft activity at airports. A number of technically challenging problems exist, each of which can be independepently overcome with existing technology. One of these is a requirement to operate at temperatures as low as -50°C. Another is the requirement to be operational at airstrips that may not have any power outlets. A third problem is one of communications between the sensor and the control processor. Besides these, the system must meet a number of other environmental requirements like the ability to operate in adverse weather conditions, be frangible if placed near runways, satisfy the height requirements for structures at or near airports, and so on. This study indicates that the most stringent requirements need to be met at only a small fraction of airports. For most airports, the total cost of the installation may be reduced by relaxing one or more of the environmental requirements, without adversely affecting the performance of the system. As an example, consider Ottawa International Airport. It is true that temperatures do not fall below -40°C, and power will be available at or near runways, because all the runways are lit. Thus, for airports like Ottawa, it would be overkill to design for -50°C, and battery operation. At the same time, it would not be wise from an engineering point of view to design separate systems to meet varying needs. A more suitable approach would be to design for the requirements of the majority of the airports, and to design add-on options that could be used for extreme conditions. One such option being actively investigated is a suitable power pack, for use at remote unpowered runways. These options have been presented in Section 8. This section discusses various recommended hardware and software solutions to an aircraft counter that meets the requirements for the majority of airports.

9.1 Sensor Selection

It is recommended that both FM-CW radars and acoustic gates, discussed earlier, be considered for the development of aircraft counters. For purposes of evaluation, a system using both sensors is recommended. The results of field tests may be used to decide whether one of these, or a combination, should be part of the production model.

9.2 Communications links

It is recommended that the aircraft counter be used in the configuration in which each end of the runway has a separate counter.

In this way the problems of communication between the ends of runways and the air terminal building (or other location) is avoided. However, in future installations, it may be necessary to interconnect the various sensors to a central processor. In that case, it is recommended that twisted cable pairs be installed for communication. It may be possible to use existing ducts near runways to pipe the cables to the required locations. Other communications links, like line-of-sight microwave, are not recommended because they are intrusive.

9.3 Control Processor Hardware

The control processor would reside in a sheltered environment within the airport complex. Power would be readily available to such a system, although it would not necessarily be immune to power failures. Thus, any commercial processor can be used as the control processor. The IBM-PC, with enough expansion capability, would form an inexpensive and suitable hardware base for the control processor. The recommended configuration would be an IBM -PC/XT, with 640 KBytes of RAM; a 20 MByte Winchester Disk; a real-time battery operated clock; a suitable monitor; serial interfaces; and a modem interface. All this hardware is readily available, and very reliable. In addition to this bought-out hardware, an interface to the sensors is needed. This could be a very simple serial multiplexer. It would have to handle at most 20 sensors (or sensor pairs), if there are at most 10 runways per airport , or control processor. Of course, these can never be all used simultaneously. The design of this interface is simple, if simultaneous events are not permitted. This interface is the only digital hardware to be designed for the control processor.

9.4 Control Processor Software

The software for the control processor accepts data from the counters, in a centralized configuration. There is no real need for multitasking software, provided a key-stroke or input through the modem can be recognized by the executive routine. This routine could then call other routines, like the local-user interface, or the remote-user interface. There is now a possibility that event counts can be missed. This is easy to overcome by allowing buffering of the sensor inputs, either at the sensor end or within the control processor.

Implementation of the control processor software may be accomplished using the standard DOS operating system, with a suitable language compiler. It is the policy of Transport Canada that all software shall be developed in Ada, or that a clear migration path to Ada be provided. The only optional languages are C and Pascal. In either case, Ada shall be used as the program development language. In order to keep costs down, it is recommended that Ada be used only as a PDL. It is recommended that Microsoft C, Microsoft Assembler (MASM) and related Microsoft software be used for development. Similar packages by other suppliers may also be suitable. Among languages, C

is recommended because it is a powerful high level language that is also structured. Pascal suffers a disadvantage in that it is not sophisticated in its error handling capabilities; and Ada is overkill for this particular application.

9.5 Power Sources for Sensors

It is recommended that, where primary power is not readily available, battery packs be used. These would operate to -40°C. The packs would consist of rechargeable batteries in dual packs, so that one can be recharged while the other is being used. A solar array may be considered for charging the batteries.

9.6 Low Temperature Operation

For low temperatures, below -40°C, rechargeable batteries are not suitable. It is possible to use primary batteries, as sole source of power. However, these are expensive. They are needed only for very low temperature operation, at airports that have no power outlets near the ends of runways. There are few such cases. Where primary power outlets are available, it is recommended that heaters be installed in the enclosures holding the electronics, to allow extremely low temperature operation.

9.7 Frequency Allocation

One disadvatage of the proposed radar system is that it is active, transmitting low power electromagnetic radiation at about 2 GHz. This means that a licence from the Department of Communications (DOC) will be required for TC to use the radar. It also means that the frequency used will be decided by DOC.

In order to overcome these difficulties, it is necessary to ensure that the radar design is such that the frequency can be changed, if necessary. This has been done in the design of the radar sensor. Although the calculations were done assuming 2 GHz for the centre frequency, the design is not critically dependent on this. The sensor can use any frequency, preferably in the range of 1 to 3 GHz.

The Department of Communications was contacted, to ensure that the proposed radar solution would be licenced. There are two possible approaches to the licensing. It is possible to obtain an experimental licence, which would have to be renewed yearly. This is not difficult. The other approach would be to apply for a permanent licence. The fact that the FM-CW radar emits low power, and that the frequency is not critical, helps. It has been suggested by TC that one possible frequency band that can be used at a future date is the 1250 to 1350 MHz band currently allocated to ground based primary radar. Another

possibility is to get allocation for a frequency that is not used around airports, but allocated for some other location, or purpose.

DOC also mentioned that modifications to the Radio Act are contemplated that would remove the requirement for licencing low power (less than 100 mwatt) transmitters. It is thus likely that in a few years a radar like the FM-CW radar proposed may not require licencing.

Thus, it appears that licencing will not be a problem. Moreover, there are frequency bands that can be used, like the 1250 MHz -1350 MHz band.

Glossary

Accelerometer	A device designed to measure only forces or accelerations.
A/D Conversion	Analog to digital conversion.
AGC	Automatic Gain Control.
ASCII	American Standard Code for Information Interchange. This code, in 7-bit form, is widely used in computer and communications applications.
Beamwidth	The width of a beam at the half-power (3dB) level.
Byte	An 8-bit unit of storage.
CAL	Canadian Astronautics Limited.
Checksum	A truncated sum of a number of bytes, used to detect errors in transmission.
Circulator	A device used in RF to isolate radiation going in opposite directions. This allows simultaneous transmission and reception.
CMOS	Complementary Metal Oxide Semiconductor.
CW	Continuous Wave, a term used to denote continuous waves, as opposed to pulsed emission.
DOC	Department of Communications.
Doppler	The effect by which a shift in frequency is produced by radial movement of the target.
DOS	Disk Operating System.
DSS	Department of Supply and Services.
FAR	False Alarm Rate.
FM-CW	Frequency Modulated Continuous Wave.
ID	Identification.
IF	Intermediate Frequency.
MTI	Moving Target Indicator.
Non-volatile Memory	Memory that does not lose its contents when power to it is switched off.
Op Amp	Operational Amplifier.
PC	Personal Computer.
PCB	Printed Circuit Board.
PROLOG	Name of a computer products manufacturer.
RAM	Random Access Memory.
ROM	Read Only Memory.
RCVR	Abbreviation for "Receiver".
RF	Radio Frequency.
SMA	A name given to an RF connector of specific dimensions.
STC	Signal Time Correction - the compensation applied to the strength of a radar return, to take into account the diminishing of the signal strength due to range. This is sometimes referred to as RVG - Range Variable Gain.
STD	Abbreviation for "Standard". It is also the name given to a computer bus.

TC	Transport Canada.
TDC	Transportation Development Centre.
Transceiver	Transmitter-receiver combination.
T/R	Abbreviation for Transmitter/Receiver.
VCO	Voltage Controlled Oscillator.
VLF	Very Low Frequency (10 - 50 KHz).
Waveguide	A rectangular tube used to pipe RF radiation. The dimensions of the tube depend on the wavelength for which the waveguide is designed.
XMTR	Abbreviation for "Transmitter".